Might some Gamma Ray Bursts be an observable signature of natural wormholes?

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The extragalactic microlensing scenario for natural wormholes is examined. It is shown that the main features of wormhole lensing events upon the light of distant Active Galactic Nuclei (AGNs) are similar to some types of already observed Gamma Ray Bursts (GRBs). Using recent satellite data on GRBs, an upper limit to the negative mass density – $\mathcal{O}(10^{-36})$ g cm^{-3} – under the form of wormhole-like objects is presented.

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I. INTRODUCTION

Ten years after the seminal paper by Morris and Thorne [1], we face the following situation: there is no observational evidence supporting the existence of natural wormholes nor serious theoretical reasons for its impossibility [2]. Black holes shared such a status during years until the discovery of galactic X-ray sources and quasars in the 1960s. Wormholes, entities that warp spacetime in such way as to provide shortcuts to separated regions of the universe or even a way to allow a backward time travel, require the violation of the energy conditions (technically speaking, the null energy condition) in order to exist. The energy conditions are conjectures that are widely used to prove issues concerning singularities and black hole thermodynamics; they constitute just plausible statements, like the positivity of the energy density. However, several situations in which the energy conditions are violated are known; perhaps the most quoted of them is the Casimir effect. These violations are typically very small (of order $\hbar$) and it is far from clear whether there could be macroscopic quantities of this kind of *exotic* matter. Nevertheless, there is nothing really compelling to prevent its occurrence and wormholes might naturally exist [3,4].

Very recently, the consequences of the energy conditions were confronted with possible values of the Hubble parameter and the gravitational redshifts of the oldest stars in the galactic halo [5]. It was deduced that for the currently favored values of H_0, the strong energy condition should have been violated sometime between the formation of the oldest stars and the present epoch. On the other hand, negative gravitational masses (underdensities in the primordial universe) have been proposed as an explanation of the voids observed in the extragalactic space [6]. An early universe cosmic network of wormholes has also been suggested as an alternative solution for the cosmological horizon problem [7]. Mann [8] have found, in addition, that dense regions of negative mass can undergo gravitational collapse, ending up in exotic black holes that could populate the universe contributing to the bulk of total dark matter. All these works clearly show that it is at least possible that natural wormholes or other negative mass objects might exist. Then the study of their possible observational effects deserves serious consideration. Although no universal mechanism to generate a relic density of exotic matter is well established at present (because of our ignorance of quantum gravity laws), several interesting ideas have been recently proposed in the literature, like, for instance, the enlargement of wormhole throats –via inflation– from the quantum foam to macroscopic sizes [9]. Despite current theoretical speculations suggest that the existence of compact objects of negative mass is plausible, their amount has not been yet constrained by observations. To provide such a constraint is the main goal of this paper.

As far as we are aware, the first observational proposal to search for natural wormholes or similar gravitational negative anomalous compact objects was presented by Cramer et al. [10] (see also Ref. [11]). They suggested that gravitational microlensing effects of these objects upon the light of background stars could produce MACHO*-like events [12], although with different (asymmetric) temporal profiles. Partial analysis of the results of several ongoing microlensing monitoring programs seems to show that wormhole-like objects are not present in the dark halo of our galaxy. (Hereafter, when speaking of negative masses, we shall think in this ingredient as always threading a wormhole. Although this can be relaxed for the development and analysis of the ideas to be considered, we shall do it just because it can provide useful numerical estimates and a pretty theoretical framework).

In this paper we shall study the microlensing scenario for an extragalactic natural wormhole acting upon light coming from an Active Galactic Nucleus (AGN). It will be shown that such anomalous microlensing event would produce lightcurves very similar to some already observed Gamma Ray Bursts (GRBs) [13] and that this can be used to constrain the amount of negative mass in the uni-

*MACHO: massive compact halo object.

verse. Preliminary results on this issue were introduced in [14] and briefly commented on in [15].

The paper is ordered as follows. The next section will review the relevant observational characteristics of the GRB phenomenon. Sec. III will deal with the negative mass lensing formalism. Afterwards, we shall analyze the consequences of negative-mass microlensing with an AGN as background source in Sec. IV. The possible nature of the lenses is treated in Sec. V, while the BATSE database is briefly discussed in the Sec. VI. The final two sections deal with the cosmological consequences of a negative mass distribution of compact objects and the conclusions.

II. GAMMA RAY BURSTS

Gamma ray bursts are flashes of high energy radiation that can be brighter, during their brief existence, than any other gamma ray source in the sky. The bursts present an amazing variety of temporal profiles, spectra, and timescales that have puzzled astrophysicists for almost three decades [13]. In recent years, our observational insight of this phenomenon has been dramatically increased by the huge amount of data collected by the *Burst and Transient Source Experiment* (BATSE) on board the *Compton Gamma Ray Observatory* (CGRO), a satellite launched by NASA in 1991. BATSE observations have confirmed that no large clustering or anisotropies are present in the sky distribution of GRBs (see Ref. [13] and references therein). We shall give a brief account of the most relevant characteristics of GRBs below.

- **Temporal Profile:** The temporal distribution of the bursts is one of the most striking signatures of the GRB phenomenon. There are at least four classes of distributions, from single-peaked bursts, including the fast rise and exponential decaying FREDs, their inverse or anti-FREDs to chaotic structures. There are well separated episodes of emission, as BATSE triggers # 1235 or # 222 and bursts with extremely complex profiles, as # 160 or # 404. Most of the bursts are time asymmetric but some are symmetric, as # 408.

- **Timescales:** Burst timescales go through the 30ms scale to hundreds of seconds. The measurement of these timescales is a rather complicated task, since it may depend on the intensity of both the background and the source. At high energies ($>$ 100 MeV), some extremely long bursts have been detected. For instance, GRB 940217 showed a high energy photon ($\simeq$ 20 GeV) 1.5 hours after the bulk of the detection.

- **Spectra:** A unique and common characteristic of GRBs is that most of their power is received in energies higher than 50 KeV. Their spectrum approximately follows a power law $N(E) \propto E^{-\beta}$, with $\beta \in (1.7, 2.7)$. It is interesting to note that there is no correlation between the spectral index and the morphology of the temporal profile or the location in the sky.

A special issue relevant for the ideas to be presented is the possible repetition of the bursts. Before BATSE was launched, repetition was analyzed by Schaefer and Cline [16], who provided two timescales for repetition corresponding to monoluminous or multiluminous sources. More recently, Quashnock and Lamb [17] found that a significant fraction of the GRBs in BATSE 1B catalogue could repeat over timescales of months. They found that many GRBs are grouped within angular scales smaller than 4^o, which is the mean error in position of BATSE detections [18]. However, a similar statistical technique was used by Narayan and Piran [19] to prove that there are also an important fraction of GRBs with antipodal positions, thus suggesting that any statistical bias or selection could produce both effects. Other preliminary tests made by Petrosian and Efron [20] and Strohmeyer et al. [21] suggested that there are some repetition in the sample with timescales of years in about 20% of the bursts at most. It was also pointed out that a failure in the CGRO tape recorders could have hidden some repeating sources [13].

More recently, another statistical work concluded that the number of repeated bursts cannot be larger than 7% of the sample [22]. The most recent and complete repetition study on the BATSE catalogue has been carried out by Tegmark et al. [23]. They analyzed the angular power spectrum of 1122 GRBs finding that no more than 5 % can be labeled as repeaters at the 99 % confidence level. By now, evidence for repetition is very suggestive but, perhaps, not compelling. This point might be clarified with forthcoming technologies, especially when detectors with improved spatial resolution become available and studies on individual GRB repetition can be made unambiguously.

The isotropic distribution of GRBs strongly suggests an extragalactic origin which has been recently confirmed by the direct measurement of high-redshifted absorption lines of the optical counterpart of the GRB 970508 [24]. If the sources are so far, the energy necessary to produce the observed events by an intrinsic mechanism is astonishing: about 10^{51} erg of gamma rays must be released in less than 1 second [25].† The most popular model to date to produce such an event is the merger of two compact stars (two neutron stars or a neutron star and a black hole) in a distant galaxy. As a result of the merging, a relativistic expanding fireball is formed. It is

†The observed flux F of a source at a distance d is related with the intrinsic luminosity L by $L = 4\pi d^2 F$.

believed that the interaction of the blast with the surrounding medium produces lower energy (X-ray, optical, may be radio) counterparts of the original GRB; again, the reader is referred to [13] for a survey of the current literature. This fireball paradigm, however, is not free of problems, as can be seen, for instance, in Ref. [26].

The wide variety of burst profiles, the statistical evidence for GRB repetition and some spectral properties remain unexplained by an unique, consistent model. There is such a large variety of individual events that every model proposed has to face a large number of counterexamples. These facts are suggesting, perhaps, that the origin of such a complex phenomenon might have more than one explanation. In fact, this idea was recently proposed in [27], where it was concluded that two or more distinct groups of bursts, probably of different origin, could be classified.

Ten years ago McBreen and Metcalfe [28] proposed that GRBs could be due to microlensing of background AGNs. At that time there was no direct observational evidence for that AGNs, like quasars and BL Lac objects, were strong gamma ray emitters, which is now a well established fact [29]. However, their model was ruled out due to the fact that most of GRBs are time-asymmetric [30], which is incompatible with microlensing by ordinary matter. In spite of this, gamma ray emitting AGNs can be outstanding background sources for producing extrinsic GRB-like events if their radiation is gravitationally focused on the observer. This focusing effect must be provided by interposed lenses made of exotic, negative mass matter which can thread, for instance, a wormhole structure. As we shall see, individual amplification events are not necessarily time-symmetric in such a case, and repetition can occur as a consequence of different caustic crossing within some source-lens-observer configuration. Moreover, the expected high energy spectral features and the lower energy manifestations of the phenomenon are strikingly similar to some already observed GRB events.

III. NEGATIVE MASS LENSING

We shall briefly review now some concepts of gravitational lensing by negative masses. The assumed geometry is that of an extragalactic wormhole of negative mass $-M$ crossing with velocity V the line of sight to some distant AGN. We shall follow the presentation given by Cramer et al. in Ref. [10] but we shall take into account the extragalactic nature of the lensing.

The Einstein radius of a negative mass is given by

$$R_e = \left(\frac{4GMD}{c^2}\right)^{1/2}, \tag{1}$$

where, aside from the usual meaning of the constants c and G, D represents an effective lens distance. This is a model-dependent parameter; in particular, it varies for different values of H_0 and Ω_0, the Hubble constant and the energy density parameter at the present time, respectively. The general expression for D is

$$D = \frac{D_{ol} D_{ls}}{D_{os}}, \tag{2}$$

where D_{ol}, D_{ls} and D_{os} are the observer-lens, lens-source and observer-source angular diameter distances, all them computed as in [31]

$$D(z_i, z_j) = \frac{2c}{H_0} \frac{(1-\Omega_0 - G_i G_j)(G_i - G_j)}{\Omega_0^2 (1+z_i)(1+z_j)^2}, \tag{3}$$

with

$$G_{i,j} = (1 + \Omega_0 z_{i,j})^{\frac{1}{2}}, \tag{4}$$

and z_i the cosmological redshift of the object i.

The variability timescale T of a microlensing event is defined as the time that takes the line of sight to the source to cross the Einstein radius of the lens: $T = R_e/V$. The overall relative intensity $\mathrm{I_{neg}}$ is the modulation in brightness of the background source detected by the observer. This is given by [10]

$$\mathrm{I_{neg}} = \frac{B^2 - 2}{B\sqrt{B^2 - 4}}, \tag{5}$$

where

$$B(t) = B_0 \left(1 + \left(\frac{t}{t_v}\right)^2\right)^{1/2}. \tag{6}$$

Here, B_0 is the time-dependent dimensionless impact parameter and t_v is the transit time across the distance of the minimum impact parameter, $t_v \propto T$. Taking $\mathrm{I_{neg}} = 0$ for $|B| < 2$, it is possible to obtain the light enhancement profile for a negative amount of mass M. These curves, see Fig. 1, must be divided in two groups. For $B_0 > 2$, the light profiles are similar to the positive mass cases but provide larger light enhancement than that given by a similar amount of positive mass. For $B_0 < 2$, curves are sharper and present brief light enhancement; they have divergences (caustics) of the intensity and then an immediate drop to zero. This happens at two given times, solutions of $B^2 - 4 = 0$; thus, for time running from $-\infty$ to $+\infty$, and during the same microlensing event, we obtain two divergences and two drops, of specular character. This is seen by the observer as two bursting events separated by a time $\sim T$. Unlike the $B_0 > 2$ case, these individual bursts present light profiles asymmetric under time reversal.

A critical requirement for such a microlensing event to occur is that the size of the background source projected onto the lens plane must not be larger than the Einstein ring of the lensing mass [32]. Otherwise, light from outside the Einstein ring would smoother out the gravitationally induced variability. Background sources whose size is a fraction of the Einstein radius are then amplified

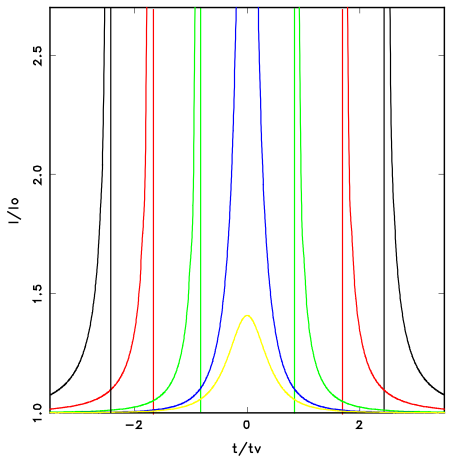

FIG. 1. Overall relative intensity I_{neg} for a microlensing event provided by negative amounts of matter. From the corners of the graph towards the centre, the curves corresponds to B_0 =0.5, 0.75, 1, 2 and 2.2.

by significant factors, while sources whose projected sizes largely exceed the Einstein radius are negligibly amplified. Since AGNs have emission regions of different scales for different radiation wavelengths, the spectrum of an observed microlensing event will depend on the mass of the lens as well as on the involved redshifts.

Finally, it is important to note that a point source is amplified by an infinite amount at a caustic crossing, but any physical extent leads to finite amplifications [33]. This *point-mass* infinity also happens in the Einstein ring of a positive point mass configuration.

IV. AGNS AS BACKGROUND SOURCES

AGNs are compact extragalactic sources of extraordinary luminosity. They can radiate as much energy per unit of time as hundreds of normal galaxies. Most of this energy comes, however, from a region much smaller than the mean distance between two stars in our galaxy. Although AGNs emit across the entire electromagnetic spectrum, from radio to gamma rays, recent observations by two instruments on board the CGRO, the *Compton Telescope* (COMPTEL) and the *Energetic Gamma Ray Experiment Telescope* (EGRET), have shown that many of these objects radiate most of their power in the form of gamma rays (see, for instance, Ref. [34] and references therein).

In spite of the existence of many classes of AGNs like quasars, BL Lac objects, Seyferts, and others, it is widely accepted that the same basic mechanism operates in all of them. This standard working paradigm of AGNs assumes that the central engine powering these objects is a supermassive ($\sim 10^8$ M$_\odot$) black hole + accretion disk system. Energy is generated by gravitational infall of material which is heated to very high temperatures in the dissipative, optically and geometrically thick disk. Along the rotational axis of the system two jets of ultrarelativistic electron-positron plasma are collimated by a yet not well-established mechanism. The emission signatures of these jets, however, are clearly detected by interferometric radio observations in many objects [35]. The several classes of AGNs are usually interpreted as a viewing effect due to the basic anisotropy of the phenomenon.

The inner part of the accretion disk emits X-rays. The origin of this X-rays is not quite clear, but it is commonly thought that the UV/optical continuum emission from the disk is up-scattered in energy by inverse-Compton scattering off relativistic electrons in a hot corona surrounding the disk, a process referred to in the literature as 'Comptonization' of the input (UV/optical) spectrum [36]. A purely thermal origin, however, cannot be completely ruled out. Anyway, the jets must traverse throughout this external radiation field. Inverse Compton interactions between the relativistic leptons that form the jets and the ambient photons produce gamma rays which, due to the relativistic bulk motion of the source, are Doppler enhanced in the beam direction. Probably, the accretion disk is not the only source of seed X-ray photons, being these additionally produced in the jet itself by synchrotron emission and also reprocessed in a surrounding halo of dense clouds (see Ref. [37] for details). Anyway, the compactness of the observed gamma ray source will be limited by gamma ray absorption in the UV-X-ray ambient field due to pair production.

The requirement that the pair production opacity to infinity equals unity naturally defines gamma-spheres of radius r_γ for a given gamma ray energy E_γ [37,38]: no gamma rays with energy higher than E_γ can be observed from radii smaller than r_γ because they would be absorbed by pair production. Notice that the sizes of the successive gamma-spheres increase for increasing energies of the observed photons. This fact has important consequences for gravitational lensing: the high energy spectrum will be differentially amplified, presenting a cutoff at energies for which the size scales of the gamma-spheres exceed the Einstein ring of the lens. The observer should see a gamma ray burst when the line of sight to the AGN intersects a caustic, with a similar spectrum to the original source at lower energies (keV to MeV) but with a cutoff at higher energies (GeV to TeV). AGN's high energy spectra are well represented by power a law $F(E_\gamma) \propto E_\gamma^{-\alpha}$, with α in the range 1.5-3.0 [34], remarkably similar to many GRBs detected by BATSE and EGRET. It is also interesting to notice that high energy continuum spectra of GRBs present a cutoff at energies of a few GeV [13].

Optical emission is originated by synchrotron mechanism in the jets of AGNs. The optical region can be coextensive with the outer gamma-spheres [37] and, due to the acromaticity of gravitational light bending, simultaneous or quasi-simultaneous optical bursts can be expected for a microlensing event. Due to the larger size of the emitting region, the optical flare will have also larger timescales than those associated to the inner gamma-spheres. Radio emission, instead, is originated far down the jet, in regions where the plasma density is considerably lower (around 1 parsec from the black hole). In most cases such sizes might exceed the Einstein radius of potential small microlenses leading to GRB-like events without counterparts at radio wavelengths.

Summing up, the central region of AGNs is a suitable background source for microlensing by compact extragalactic lenses. The resulting events, if some of the lenses are wormhole-type objects, should very much resemble GRBs: brief flares of gamma rays, with power law continuum spectra and X-ray to optical counterparts, in many cases on larger timescales. The event-averaged high energy spectrum is remarkably similar to a typical AGN-spectrum. Moreover, the total duration of some extremely large events, including the detection of very high energy photons at the end, could be exactly what one would expect from microlensing: since the most energetic gamma-spheres are the bigger ones, their crossing time must be larger. In other cases, like GRB 970111, no X-ray or optical emission have been detected despite the bursts were well in the field of view of very sensitive instruments like the Beppo-SAX satellite. This fact can be a straightforward consequence of the relatively large sizes of the corresponding emitting regions when compared with the inner gamma-spheres.

V. WORMHOLES AS NEGATIVE MASS LENSES

In order to get a feeling of the involved magnitudes in a wormhole microlensing event let us consider a concrete example. We shall focus on the model assuming $H_0 = 100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, $\Omega_0 = 1$ and a cross velocity for the extragalactic lens equal to 5000 km s^{-1}. Defining $D = (2c/H_0)\mathcal{D}$, we find

$$R_e = 1.04 \times 10^{12} \left(\frac{M}{M_\odot}\right)^{1/2} \mathcal{D}^{1/2}\ \mathrm{km}. \tag{7}$$

Table I shows some negative masses required to get a particular variability timescale T, for a given configuration of lens-source redshifts, along with the corresponding Einstein radius. Due to the size constraints on the AGN's emitting region previously mentioned (Sec. III), we have

$$x \leq 2R_e \frac{D_{os}}{D_{ol}}, \tag{8}$$

where x is the linear size of the emitting region in the core of the AGN. Replacing R_e we get a constraint over the mass of the possible lenses:

$$M \geq \frac{c^2 x^2}{16\,G}\ \frac{D_{ol}}{D_{os} D_{ls}}. \tag{9}$$

Considering that the typical size of the gamma-spheres for energies of ~ 1 GeV are $x \sim 10^{-3}$ parsecs [38], we find in the case of the redshifts quoted in Table 1 that $|M| \geq 1.27 \times 10^{-3} M_\odot$, and thus one should expect that burst repetition due to crossing of the two different caustics in a single event should take several months, even for substellar wormhole masses.

TABLE I. Typical negative masses for a lens-source redshift configuration given by $z_l = 0.25$ and $z_s = 2.5$ in order to provide each of the variability timescales. The corresponding Einstein radii are also shown. It was assumed a low extragalactic velocity equal to 1000km s^{-1}.

T years	$-M/M_\odot$	R_e km
1/12	9.68×10^{-5}	2.59×10^{9}
1/2	3.50×10^{-3}	1.55×10^{10}
1	0.014	3.15×10^{10}
10	1.430	3.15×10^{11}

We shall show now that these stellar and substellar masses are attainable with a simple wormhole configuration. We shall use a well known example of wormhole geometry, the absurdly benign wormhole, introduced in [1]. This special kind of wormhole is a solution of the Einstein field equations corresponding to the metric

$$ds^2 = -dt^2 + \left(1 - \frac{b(r)}{r}\right)^{-1} dr^2 + r^2 d\Omega_2^2, \tag{10}$$

with

$$b(r) = b_0 \left(1 - \frac{r - b_0}{a_0}\right)^2, \qquad \text{if}\ \ b_0 \leq r \leq b_0 + a_0, \tag{11}$$

$$b(r) = 0, \qquad \text{if}\ \ r > b_0 + a_0. \tag{12}$$

In this solution, b_0 is the throat radius and a_0 is a cut-off in the energy density; space-time is empty for $r > b_0 + a_0$. The timelike field equation is

$$\rho = \frac{b'}{8\pi G r^2}. \tag{13}$$

From (13) we can integrate for $b(r)$ and define a mass function by

$$b(r) = b(r_0) + \int_{r_0}^{r} 8\pi G \rho r^2 dr \equiv 2Gm(r), \tag{14}$$

which yields the total mass of the wormhole [2],

$$\frac{M}{M_\odot} = 0.337\, b_0 \left(1 - \left(\frac{b_0}{a_0}\right)^2\right). \tag{15}$$

The numerical factor arises from the use of solar mass units while the radius is given in km. Note that this mass is not necessarily negative, and it depends on the relationship between the values of b_0 and a_0. This does not mean that null energy condition (NEC) is not violated, because some of the other two inequalities of this condition need to fail: there are no wormholes fulfilling

TABLE II. Masses for the absurdly bening wormhole.

b_0 (km)	a_0 (km)	$-M/M_\odot$
1	0.50	1.011
5	4.99	1.34×10^{-3}

NEC. Table II presents some illustrative numerical values of the parameters in this simple configuration. However, it is important to remark that this solution is by no means special; other geometries can account for stellar-size masses, without being spherically symmetric [39].

Since wormholes connect two otherwise separated asymptotic regions, there are two asymptotic masses which can, in general, differ. Exchange of matter between both wormhole mouths can modify their mass ratio starting a process that could lead to a large (stellar-size) negative mass in one of the mouths [2,10]. We expect that the computation of masses with (14) will be possible whenever the stress-energy tensor is confined to some fixed radius, in such a way that spacetime becomes vacuum and described by a piece of Schwarzschild solution.

VI. ON BATSE DETECTIONS

Distinctive features of wormhole microlensing are repetition of the event and a definite asymmetry in the profiles of the repeaters: the initial bursts are anti-FREDs whereas their counterparts are FREDs. A study of the temporal asymmetry in the BATSE database, then, can be useful to enlighten the role played, if any, by microlensing in the production of GRBs.

The time asymmetry of a GRB lightcurve can be quantitatively estimated using the third moment of the time profile given by

$$\mathcal{A} = \frac{< (t- < t >)^3 >}{< (t- < t >)^2 >^{3/2}}, \tag{16}$$

where the brackets denote average over all data weighted with the number of counts. For a time symmetric burst results $\mathcal{A} = 0$, while those bursts with faster rises (falls) than falls (rises) present $\mathcal{A} > 0$ ($\mathcal{A} < 0$). A determination of $\mathcal{A}$ for a sample of 631 bursts from BATSE 3B catalogue [40] shows that 32 % of the profiles present $\mathcal{A} < 0$. This result clearly means that *microlensing by wormholes cannot be the only physical mechanism behind the GRB phenomenon.* Since fireballs naturally account for short rising times they are the best candidate to explain most of the events. However, the formation of the fireball requires a sudden release of energy which is radiatively dissipated during the blast wave expansion and, consequently, GRBs with $\mathcal{A} << 0$ remain unexplained.

Bursts with $\mathcal{A} < 0$ cannot be directly considered as tracers of wormholes because not all of them repeat. As we have mentioned in Sect. II, the whole sample is consistent just with a 5 % of repetition. This means that just about 56 out of 1122 events in the BATSE 3B catalogue could be originated by wormholes. The identification of these individual bursts cannot be made unambiguously because of the large positional error boxes of BATSE measurements. We shall discuss here some candidates.

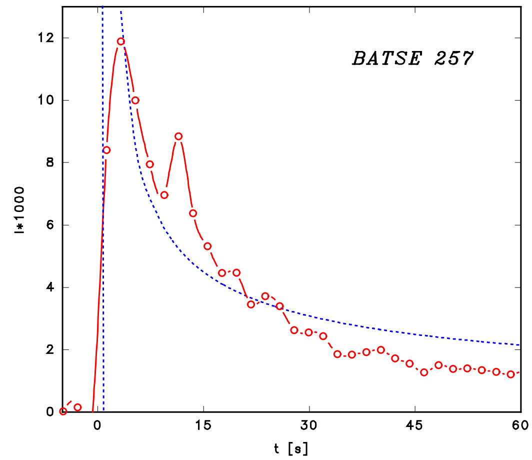

FIG. 2. This is BATSE Trigger #257. The hollow circle points represent the summed number of counts of the total number of channels of the two triggered detectors (det. 1 and 2.). The dotted curve is a theoretical curve I_{neg} with the following values: $t_v = 1.09 \times 10^8$s, $I_0 = 2.81$. The position of the theoretical caustic is 1.63 s.

Fig. 2 shows BATSE trigger # 257 (GRB 910602 [18]) which was detected a couple of months after the start of the space mission. It is a typical, single-profile, clearly asymmetric GRB. Its duration was $\sim$ 80 s, with a peak flux of $\sim$ 1.7 photons cm^{-2} s^{-1}. This kind of event could be produced by a single wormhole microlensing occurrence with dimensionless impact parameter $B_0 < 2$. In Fig. 2, we have superimposed to the observational lightcurve, a theoretical microlensing curve. The timescale of the microlensing event is $T \sim 3.2$ years.

Since the event asymmetry corresponds to a second-caustic crossing, a similar event with opposite asymmetry, corresponding to first-caustic passing, should have occurred in April 1988, three years before CGRO launching. Assuming the set of redshifts and velocity mentioned in Table 1, we find that a wormhole of mass $M \sim -0.146\, M_\odot$ might have been responsible for the event. Similar results may be obtained for other triggers.

Some remarkable GRBs in the database, from the point of view of wormhole microlensing, are BATSE triggers #1653 (June 17 1992, at $l^{II} = 131.18°$, $b^{II} = -41.25°$) and #2110 (December 30 1992, at $l^{II} = 132.91°$, $b^{II} = -42.87°$). A symmetry analysis using (16) shows that, when the background is subtracted in such a way that the peak structure is emphasized over that of the surrounding foothills, the bursts present an anti-FRED–FRED structure [41]. In addition, the position error boxes for these GRBs include three AGNs, namely PG 0117+213, 0109+200, and the BL Lac object 0109+224. This particular object has been detected at high energies by ROSAT and other satellites [42] and there are many reports of its fast variability at different wavelengths [43]. It is, consequently, an excelent candidate for background source in a wormhole microlensing event. Unfortunately, its redshift is unknown at present so we cannot infer from the event timescale ($T \sim 6.5$ months) a range of possible masses for the lens. If a redshift $z = 1.5$ is assumed and the wormhole is halfway, then the mass of the wormhole results $-0.12 M_\odot$. Calculations, however, are not very sensitive to z.

VII. COSMOLOGICAL CONSEQUENCES

At this stage it would be worth obtaining an estimate of an upper limit to the amount of negative mass that could exist in the universe. With this aim, we shall assume that the negative matter is under the form of wormhole-like compact objects, and we shall estimate the optical depth considering that GRB repeaters detected by BATSE were caused by them. This will provide a consistent upper limit on the possible number of *isolated* wormholes in the universe. Wormholes linked to galactic halos are not taken into account in this calculation and should, instead, be treated in the way described by Cramer et al. in Ref [10].

The concept of optical depth was originally introduced in the context of gravitational lensing by Vietri and Ostriker [44], and it was applied by Paczyński [45] to the problem of gravitational microlensing by objects belonging to the dark halo of our own galaxy. The optical depth to microlensing can be defined as the fraction of solid angle covered with Einstein rings of the lensing objects. If it is smaller than unity (which is certainly the case when wormholes are considered as lenses) it provides a measure of the probablity of microlensing. The total optical depth due to all lenses placed between the background source and the observer is given by

$$\tau = \frac{4\pi G}{c^2} D_{os}^2 \int_0^1 |\rho(x)|\, x\,(1-x)\, dx \tag{17}$$

where ρ stands for the mass density distribution of negative matter under the form of wormholes and $x \equiv D_{ol}/D_{os}$, [12]. Clearly, the value of τ depends on the model adopted for the distribution of lensing matter along the line of sight towards the distant sources. For simplicity, we shall adopt here a constant density. Then,

$$\tau = \frac{2\pi}{3} \frac{G\, D_{os}^2\, |\rho|}{c^2}. \tag{18}$$

$|\rho|$ is expected to be extremely small, otherwise cosmological effects concerning a wormhole-filled universe should be evident. Then, τ, the probability of detecting a microlensing event onto a given background source, is almost negligible. Fortunately, the number of background AGNs seems to be huge: about ten percent of the objects detected in the Hubble Deep Field images are of this class [46]. This makes the total number of potential background sources for microlensing by wormholes as high as 10^9. The number of events observed in a lapse ΔT is

$$N = \frac{2n}{\pi} \tau \frac{\Delta t}{T}, \tag{19}$$

where n is the total number of background AGNs and T is a typical timescale for microlensing, [45]. Then, using both previous formulae in favor of $|\rho|$, we get

$$|\rho| = \frac{3}{4} \frac{T}{\Delta t} \frac{N}{n} \frac{c^2}{G} \frac{1}{D_{os}^2}. \tag{20}$$

In (20) there are quantities of two different kinds. Most of the magnitudes involved are related to observation. We have in this group the already mentioned number of background sources and the observed number of BATSE triggers that may be associated with repetition, $N = 1122 \times 5/100$ during $\Delta t = 3$ years of operation. The angular diameter distance of the source is also fixed because cosmological distribution of AGNs seems to peak somewhere between $z_s = 2$ and $z_s = 3$, and so we can adopt an intermediate value of $z_s = 2.5$. On the other hand, we have one model-dependent magnitude, the variability timescale of the problem, T. As $T \simeq R_e/V$, we note that both, the mass and the velocity of the lens, are degrees of freedom of (20). As we want to find an upper bound on $|\rho|$ we shall choose a conservative extragalactic velocity of 5000 km s^{-1}. Regarding the mass, we saw in the previous section that a mass of $-0.1 M_\odot$ seems to fit an observed BATSE trigger and is suitable for timescales from months to years, consistently with GRB-repetition intervals. In the absence of any other clue respect to possible masses of natural wormholes we adopt this value. In the calculation we also take into account the fact that one wormhole should produce two GRBs of the sample. With these figures, we obtain

$$|\rho| \leq 9.05 \times 10^{-36}\, \mathrm{g\, cm^{-3}}. \tag{21}$$

The mass density (21) must be considered as a large upper bound on the possible amount of negative matter in the universe. Clearly, this amount is too small to produce significant cosmological consequences. For comparison, we recall that a lower limit for the mass contribution due to galaxies in the universe is 6×10^{-31} g cm^{-3}, and the critical density is of order 1.9×10^{-29} g cm^{-3} (see, for instance, Ref. [47]).

VIII. CONCLUSIONS

We have shown that microlensing events produced by wormholes with AGNs as background sources very much resemble certain types of GRBs; types that cannot be explained in standard models. We then used observational data on GRBs to determine an upper limit for the amount of wormhole-like objects in the universe. This upper limit is enough to see that negative matter hardly would have any influence in cosmology. An unusual feature of the presented scenario is that, while GRB repetition has previously been seen as a strong evidence for noncosmological origin, the microlensing model accepts it warmly: sources are cosmological and repetitions arise from different caustic crossings. This model implies that not only some bursting events must repeat, but also that they should do it with temporal profiles of specular character. This makes the model capable to be falsified. We expect that, with the improvement of the observational techniques and the increase of the GRB sample, more exact limits to the amount of the negative mass will be available. Forthcoming technologies and satellites such as the *High Energy Transient Explorer* (HETE), the next *Gamma Ray Large Area Space Telescope* (GLAST) and the current Beppo-SAX satellite will help to improve burst position measurements yielding light onto the repetition phenomenon.

Whether the laws of physics, in some deep realization, forbid the violations of the energy conditions in the large amount needed to produce stellar-size compact objects of negative matter, is something not yet clear. But, if the universe does admit wormholes geometries in it, it is very likely that some of the GRBs may be caused by a microlensing mechanism, being this one of the main conclusions of this work. As an immediate spinoff, we have the converse fact, i.e. that if there were no possible burst in a large, perhaps not already obtained sample, which could be associated with wormhole-like lensing, then it should be understood as a serious objection to the existence of anomalous compact objects in the universe.

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